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A Picosecond-Response Photoconductive-Sampling Probe for Digital Circuit Testing

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Introduction

Recent efforts in noninvasive high-frequency and high-resolution measurement techniques have led to the development of a number of photoconductive probes [1-4]. In this paper the feasibility of using the fiber-coupled, micromachined probe described in [2,3] for in-circuit testing and characterization is demonstrated by detecting waveforms at internal nodes of two different digital circuits. On the one hand, measurements have been carried out which reveal the performance of a circuit under standard operating conditions. In this case the measured electrical signals originate from an external source, *i.e.*, an rf synthesizer. In a second application, femtosecond optical pulses have illuminated one of the transistors of a circuit to generate the signal that is measured. This second approach is used to emulate so-called single-event upsets (SEU), which are usually caused by cosmic particles in satellite-based electronic systems. These effects have a negative impact on the performance and reliability of these systems and therefore are a limiting factor for their commercial implementation. In the past, optical techniques to generate SEU effects have been successfully demonstrated for testing single devices [5]. In contrast, the results presented here demonstrate the generation and detection of these effects inside a complex circuit environment. Thus, they may especially benefit the development of radiation-immune circuits.

Experimental Results

The photoconductive-sampling probe used is fabricated on low-temperature-grown GaAs and mounted on an optical fiber. Due to the integration of a JFET source follower, the probe has high input impedance and a low capacitance, so that a noninvasive probing of electrical signals is possible. The probe has a 3.5 ps response and a sensitivity of 15 $nV/(Hz)^{1/2}$ in conductive contact [2], but has also shown a 2.5 $\mu V/(Hz)^{1/2}$ sensitivity for measurements through a 4000 Å passivation layer of SiO_2 [3]. The circuits examined are a GaAs-based matrix delay chain and a InP-based, heterojunction-bipolar-transistor (HBT) frequency divider. The width of the metal probe tip is 7 µm, which is sufficient to measure the 3 µm-wide interconnects within the circuits.

Figure 1 shows a waveform measured using the photoconductive probe at an internal node of the matrix delay chain when a sinusoidal input of ~ 81 MHz is applied. An oscilloscope measurement of the circuit output waveform is also shown for comparison. In this configuration, the photoconductive probe is used as a sampling gate downconverting the rf signal into the kHz range. The *in situ* waveform observed is reduced in voltage level in comparison to the oscilloscope output signal, since the probe is sensing the signal through a thick passivation layer, but it still reveals the shape of the waveform at an internal-node position. In Fig. 2, a section of the frequency-divider circuit is shown with the location of optical fiber illumination on one of HBTs indicated. The photoconductive probe has been used to sense the photogenerated signal at various interconnect lines throughout the circuit. Several such single-event upset signals are shown in Fig. 3 (from three nodes: A, B, and C in Fig. 2). No rf signal is applied in this case, and the measurements are carried out in a pump-probe configuration. In comparison to the output of the entire circuit, which is sinusoidal at a frequency of one quarter that of the laser repetition rate, transients with rise times as short as 18 ps (node A) and as long as 28 ps (node C) have been measured within the circuit. Additionally a propagation delay of about 4 ps between the measured waveforms at successive nodes is detected inside the circuit.

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Conclusions

Results obtained with a high-speed, high-sensitivity photoconductive probe have demonstrated that internal circuit waveforms can be measured and single-event effects characterized. The probe thus has potential as a diagnostic tool for IC testing (*e.g.*, for gate delays, faults, *etc.*), even through passivation layers, with both high spatial resolution and high bandwidth.

References

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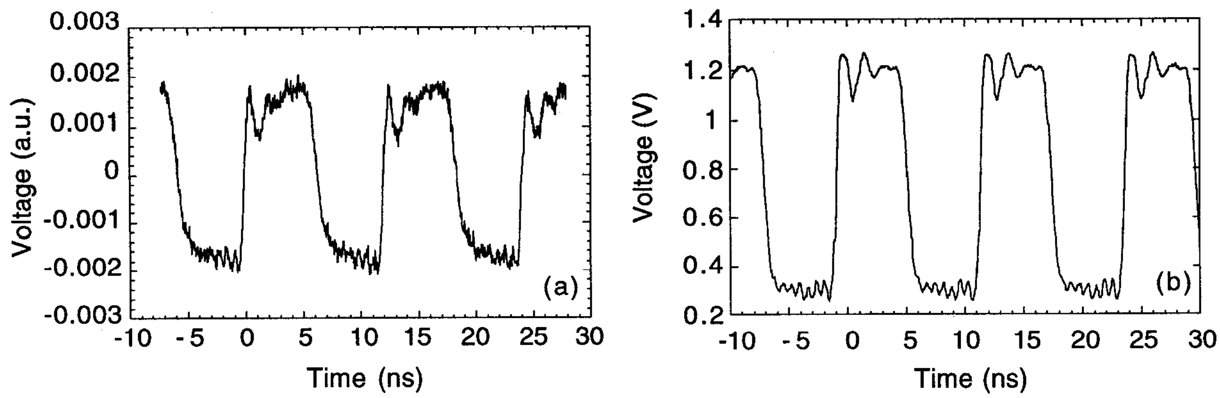

Fig. 1 (a) Waveform at internal node of a matrix delay chain with sinusoidal circuit input of 81 MHz. (b) Output of the entire circuit measured with a 1-GHz-bandwidth oscilloscope.

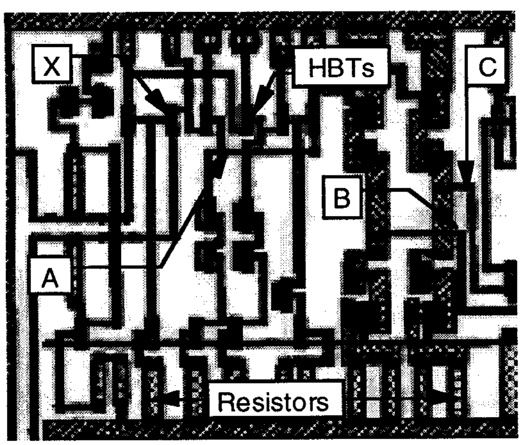

Fig. 2. Investigated inverter section of the frequency divider. The photoexcited HBT is marked with an "X." "A," "B," and "C" are three of the internal nodes probed.

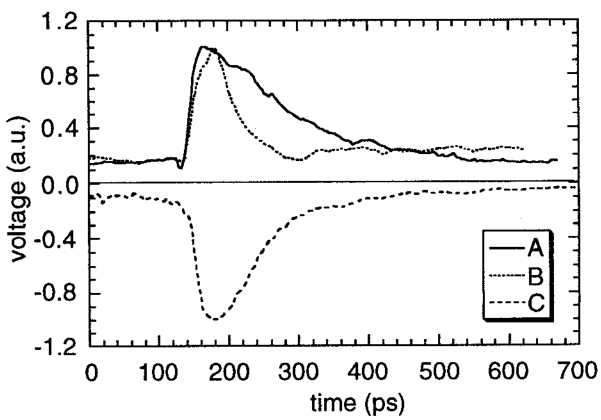

Fig. 3. Measured internal transients at positions A, B, and C (from Fig.2) as the single-event upset travels through the circuit.